WHO'S DRIVING? STRUCTURED PAIRING IN AN ELECTRONICS LABORATORY

BY

NICHOLAS D. FILA

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Electrical and Computer Engineering
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2010

Urbana, Illinois

Adviser:

Professor Michael C. Loui

Abstract

Pair programming, a method of structuring student groups in computer science courses, has been found to increase student confidence, satisfaction, and persistence in computer science courses. I developed a similar method of structuring student groups, called “structured pairing,” which I implemented in an engineering laboratory. I compared structured pairing with traditional student grouping, using an end-of-semester survey, focus group interviews, College of Engineering enrollment data, and final examination scores. I found that, like pair programming, structured pairing increased student confidence, satisfaction, and desire to persist within engineering. Structured pairing also increased student comfort with basic lab tasks, increased student willingness to work in groups or teams in the future, provided more positive and equitable experiences, and gave students a more helpful view of teamwork.

Acknowledgments

First and foremost, I would like to thank Professor Michael Loui, whose contributions to this master's thesis and to my academic development are immeasurable. Professor Loui introduced me to pair programming, helped formulate the research topic and methods, provided weekly writing feedback, provided academic and professional guidance, aided with the operation and analysis of focus groups, and most of all, supported an education-related thesis in a department focused mostly on technical research.

I would also like to thank Dr. Patricia Franke, the faculty supervisor of the ECE 110 laboratory. Dr. Franke not only allowed the research to be conducted within her lab, she was receptive to it. Her advice and supportduring my time investigating structured pairing and as an ECE 110 teaching assistant were irreplaceable.

Thank you to Dennis Matthews, Darby Hewitt, Sungwhan Shin, and the other ECE 110 TAs for participating in, and putting up with, the research.

Thank you also to Geoffrey Herman, Stephanie Seiler, and George Karavaev. Geoffrey was a wonderful resource on educational research and technical writing. Stephanie helped draft a version of the end-of-semester survey. George helped me pilot test the focus group questions.

I would also like to thank Matt and JP in the ECE Copyroom for diligent printing of paper surveys, the people of the ECE Parts Shop for keeping the ECE 110 lab equipped, and the students of ECE 110 for trying something new.

Thank you to GATE and iFoundry for financial assistance to parts of this research.

Finally, I would like thank my family and Cara. Their encouragement, love, and advice got me through some difficult times on the road to this thesis.

Table of Contents

Chapter 1: Introduction and Literature Review

1.1 Importance of Engineering Laboratory Courses

Laboratory courses are vital to engineering education. The purpose of laboratory courses is to help students learn engineering theory and practice-related skills [1]. While in lab, students refine their knowledge of fundamental concepts. They see firsthand how theory applies to actual materials and devices. Later, students use concepts they have mastered to solve practical problems and work with complex engineering systems. But laboratory courses go beyond enhancing students' understanding of engineering theory and providing them with hands-on experience.

Laboratory courses also help students build nontechnical professional skills and attitudes [1]. Students must work together in lab to accomplish their goals. While refining their theoretical knowledge and gaining hands-on experience, students also build communication skills, learn to work in teams, and develop persistence, optimism, and healthy skepticism.

Magin and Kanapathipillai [2] conducted focus group interviews with juniors and seniors in mechanical engineering to study student perceptions of engineering laboratory courses. They concluded that most students see labs as essential to their education. Students believe laboratory courses help them "see where the theory comes from" and "see how stuff really works."

1.2 Organizing Student Groups in Engineering Laboratories

Despite the importance of laboratory experience in science or engineering, little is known about how to structure student groups within these laboratory courses. Sutko [3] studied the effect of laboratory group size on academic performance in introductory materials engineering courses. Sutko concluded that two students is the optimal size of a laboratory group, while groups of four and groups of three are less desirable. Groups of five or more students were not considered. Observational data showed that groups of two would not move on within laboratory assignments until both group members understood the concepts. Groups of three moved on when only two of students in the group understood the topic. Groups of four tended to split up into separate groups of two.

Unfortunately, Sutko's study was limited to the optimal size of lab groups. He provided no explicit guidelines for interaction within the group. Perhaps the optimal group size for engineering labs is two students, but how should those students work together to maximize the benefits of the laboratory experience? Specifically, how should instructors organize laboratory groups to ensure students' participation and engagement in laboratory activities?

One solution is to assign roles within laboratory groups.

Gresser [4] studied group interaction when students had specific roles in an introductory physics laboratory. Each group contained four students, each of whom filled one of the following roles for the entire lab period: the journalist, who took notes for the group; the data interpreter, who illustrated and interpreted data; the critic, who interacted with other lab groups and made recommendations to their own group; and the checker, who supervised the creation of the lab report. The roles were intended to give each student specific responsibilities and to ensure active participation. Without strict supervision, however, students tended to ignore the complicated roles.

1.3 Pair Programming

In computer science laboratories, the pair programming method provides clearly defined roles that are simple to follow.In pair programming, students are divided into groups of two. Within each pair, students take turns in the role of the *driver*, who types the specification or program code, and the *navigator*, who oversees the driver's progress, asks questions, debugs as errors occur, and keeps the pair on task. Students switch roles every twenty minutes. Though the two roles may seem unequal, all decisions are made as a group. The driver and navigator roles resemble the *solver* and *listener* roles in Thinking Aloud Pair Problem Solving [5].

The simple, distinct roles allow students to address complex problems from multiple perspectives. As the driver, the student simply *does*. The driver is action-oriented, physically working towards a solution to the group's problem by typing in program code. As the navigator, the student observes and checks the group's work. Navigators are better situated to see the overall picture of the groups' work. Though the navigator role is less action-oriented than the driver role, navigators are still active, asking metacognitive questions and finding bugs in the code. Switching roles at moderate intervals allows students to make significant accomplishments during each session within a role, while not growing weary of either role.

McDowell et al. [6] investigated pair programming in an introductory computer science (CS) course at University of California, Santa Cruz (UCSC). Theyfound that students who pair-programmed experienced greater confidence and satisfaction, and persisted in computer science at higher rates than solo programmers (Table 1.3.1).They also found that pair programming improved the quality of student programs based on number of properly implemented features.

Pair programming also benefited groups of students who traditionally leave engineering at above average rates: women and students with below average academic potential. McDowell et al. [6] found that pair programming improved persistence among women in computer science, as shown in Table 1.1. Braught et al. [7] found that pair programming improved individual programming ability among students with below average SAT scores, which they used to measure academic potential. Unfortunately, neither Braught et al. nor McDowell et al. investigated pair programming's impact on underrepresented minorities.

Table 1.1: Persistence Rates in McDowell et al. Study

Percentage of students who passed the introductory course and…	Women (N = 51)		All Students (N = 321)	
	Pair	Solo	Pair	Solo
Majored in CS at UCSC after one year	**46.3**	**11.1**	**56.9**	**33.8**
Majored in CS at UCSC after one year among those who indicated a planned CS major at the start of the intro course	**59.5**	**22.2**	**70.8**	**42.2**
Took a second CS course within one year	61.1	50.0	**76.7**	**62.2**
Took a second CS course within one year among those who indicated a planned CS major at the start of the intro course	73.8	55.6	**84.9**	**66.7**

Bold numbers indicate statistically significant differences

1.4 Research Questions

Pair programming has proven to be effective in computer science laboratories, but could those benefits extend to engineering laboratories? Engineering laboratories are similar to computer science laboratories. In both, small groups of students work together through a set of outlined procedures or towards a common deliverable, and generally only one student at a time is able to work with the lab equipment(or computer in computer science laboratories). Given the similarity, a version of pair programming could be developed for engineering laboratories.

In this thesis project, I intended to determine whether a modified version of pair programming, called “structured pairing,” could improve student confidence, satisfaction, and persistence within engineering. I also intended to determine if those same benefits occurred within the groups with traditionally below average persistence: women, underrepresented minorities, and students with below average academic potential.

Chapter 2: Implementation of Structured Pairing

2.1 The ECE 110 Laboratory

ECE 110, *Introduction to Electrical and Computer Engineering*, is a first course in electrical and computer engineering [8]. ECE 110 is required for all electrical, computer, and general engineering majors, but is often taken as an elective by students studying computer science, physics, and other engineering disciplines. Three hundred to four hundred students enroll in ECE 110 each semester.

ECE 110 focuses on fundamental concepts in electric circuits, communications, signal processing, electronics, controls, and digital logic. Students attend three hour-long lectures on these fundamental concepts each week. Students gain hands-on experience with topics they have explored in the lectures during one three-hour-long laboratory session each week.

Each student attends the same laboratory section each week. Each laboratory section is conducted by two teaching assistants (TAs) and typically contains twenty to twenty-eight students. Students form groups of two or three to complete all laboratory assignments. Students are free to switch groups during the first four or five weeks of the semester. By the sixth week student groups become permanent.

During the first ten weeks of the semester, students conduct experiments with DC circuits, diodes, transistors, and digital logic. Each laboratory session has a specific theme—such as properties of resistors—which builds on what students learned in laboratory and lecture the previous week. Each student has a manual containing procedures and related questions for the each of the ten lab assignments. Students' grades for the first ten weeks of the ECE 110 laboratory are based solely on their answers to the questions in the manual. Students are graded independently, but because they are encouraged to discuss the questions with each other, they often produce similar answers.

The laboratory assignments culminate in a design project. Each group of students has three weeks to design and implement an autonomous robot car that follows a white tape on a black background. A final test track includes obstacles such as right angle turns and color-coded junctions where vehicles must turn left or right based on the track's color—red or white—at the junction. Students' grades for the final portion of the course depend on car performance on the final test track and a joint project report. Since students share final track performance and report grades with their group member(s), thirty percent of their course grade for the laboratory is identical among members of the same lab group.

2.2 Experience and Expectations

Before conducting any research on structured pairing, I spent two semesters as a teaching assistant in ECE 110 laboratory sections. Based on personal experience with students and informal conversations with other ECE 110 teaching assistants, I have come up with a set of observations regarding students in the ECE 110 laboratory. These observations may be applicable to students in other educational engineering laboratories.

First, most students have a positive experience in the ECE 110 laboratory. The course offers hands-on experience early in their engineering education in a relaxed and supportive setting. Nearly all students come to the laboratory eager, or at least willing, to learn. They share the work with their partners equally and they gain knowledge and experience in each of the subjects the laboratory covers. Unfortunately, a significant number of students have unsuccessful laboratory experiences.

Unfavorable experiences within the laboratory are often caused by malfunctioning equipment and procedural uncertainty. With fourteen sets of lab equipment, circuit elements, and cables shared among more than three hundred students, equipment occasionally breaks. Because students tend to assume the equipment is always functional, they often waste time or effort on ammeters with broken fuses or internally frayed BNC-to-banana cables. Additionally, students occasionally become confused and delayed by the lab procedures or performance of certain tasks. TAs are usually able to resolve these problems, but frustration and loss of time due to these setbacks often lead to unfavorable experiences among students.

Many unfavorable experiences also result from interpersonal problems within a lab group. To succeed in a laboratory, it is essential for all members of a group to contribute to the group's work and to remain receptive to challenges, compromise, and responsibility. Free riders and dominant group leaders are two recurring reasons for unsuccessful lab experiences.

A free rider is a student who does little work or contributes little to a group's success. Laboratory work is difficult to complete individually, especially for studentswith little or no prior experience in an engineering laboratory. It is essential for group members to work together equally. When groups contain free riders, the other members of those groups are forced to complete more than their fair share of lab work with less aid and guidance than they are entitled. Neither the free riders nor the free riders' partners experience the laboratory to its fullest extent. Free riders typically pass the course, if their partners are able to perform the experiments and complete the design project adequately, but they gain little of the knowledge and the hands-on experience the ECE 110 laboratory offers.

A dominant member of a lab group can produce results similar to free riders. Nearly every lab group has a leader, a student who can take charge when necessary to lead the group through a difficult challenge or setback. Some students take the leadership role to the extreme: they do not let the other students in their groups work with the equipment or take active roles in design and discussion. Hands-on experience is the primary focus of the ECE 110 laboratory. Students learn things in ECE 110 they could never learn in lecture. Students never fully experience the laboratory when overbearing leaders dominate in their groups.

Extreme cases such as free riders and dominant group leaders are rare in ECE 110. Problems within lab groups are often milder. More typical problems within lab groups include conflicts over responsibility, conflicts over final project design philosophy and implementation, poor effort, tardiness, and occasional negligence of duties. These problems can be just as serious as the more extreme cases. Conflicts over responsibility often waste time and produce ill will within groups. Conflicts over final project design philosophy and implementation can have similar results to conflicts over responsibility, and can also result in poor grades on the final project (for groups with students who continually alter their partners' designs). Occasional negligence of duties, poor effort, and tardiness are mild versions of free riders. The temporary free riders gain no experience with a specific task or piece of equipment. The goal of the course is to learn as much of the course material as possible, not to only learn what is convenient.

ECE 110 TAs can correct the problems of malfunctioning equipment and procedural uncertainty. TAs can fix or replace broken lab equipment, or send for repairs. They can also answer students' questions regarding how to proceed with their lab assignments and how to perform laboratory tasks. Unfortunately,we have not yet found proven solutions for free riders or dominant group leaders. A version of pair programming could be a solution.

2.3 Pair Programming

Pair programming is a simple way for pairs to work together efficiently on computer programming problems. Pair programming groups complete every step of creating a computer program together, from planning through execution. Each member of the programming pair takes one of two roles: the driver and the navigator. The driver is responsible for typing the specification or program code. The navigator oversees the driver's progress and keeps the pair on task. The driver and navigator roles switch every twenty minutes until the assignment is completed. Though the driver is the only group member who can make changes to the code or outline, all major decisions are made as a group.

I was encouraged by pair programming's documented success increasing confidence, satisfaction, and persistence [6], and also its potential for improving teamwork and problem solving. Pair programming forces students to work together and facilitates an equal division of labor. It allows students to approach a problem from two distinct vantages: the action-oriented, hands-on driver and the goal-focused, reflective navigator. I desired to provide a similar experience for students. I believe structured pairing achieves that goal.

2.4 Structured Pairing

Since pair programming has been successful in computer science laboratories [6], I attempted to adapt pair programming to an engineering laboratory with minimal changes. First, I changed the name from "pair programming" to "structured pairing," since laboratoryassignments for ECE 110 and many other engineering laboratories require more than programming.

2.4.1 Roles

I kept the names of the individual roles and kept the specifications for each role as similar as possible to the originals. The driver performed all of the hands-on work. In the ECE 110 lab, the driver's duties included building circuits on a breadboard, setting up and adjusting the vehicle, adjusting power sources and measurement devices, and keeping the lab station in order. The navigator's main job was to oversee the group's progress. The navigator took an active role, continually checking the driver's progress, correcting errors, and asking questions. In addition, the navigator recorded measurements from measurement devices such as the digital multimeter and oscilloscope and kept additional notes for the group.

2.4.2 Transitions between Roles

The ECE 110 lab has specifically outlined instructions for the ten weekly lab assignments. Unlike McDowell's students, who completed single, open-ended projects, ECE 110 students explore engineering concepts with shorter, guided exercises. For instance, in lab number 4 students build a series of circuits using four types of diodes: a standard p-n diode, an LED, a single package with two LEDs in reverse parallel, and a Zener diode. The students measure the circuit voltages and currents to plot the I-V curves of the diodes. They also perform additional tests on the circuits.

The instructions within each lab assignment are grouped into segments. Though some segments build upon previous ones, each has its own focus that often requires building new circuits or using new equipment. Instead of placing transitions at rigid time intervals, I felt it best for students to complete entire segments of lab assignments without being forced to break continuity. For instance, I did not want to force students to switch roles in the middle of wiring a circuit because I wanted them to have the experience and accomplishment of building entire circuits. Further, ECE 110 is a timed lab. The disruption caused by switching roles in the middle of a segment would likely increase completion time and result in added pressure on structured pairing students. More natural transitions between driver and navigator would be during breaks between segments, when the focus of the lab activities changed.

I set three to five transition points within each three-hour weekly lab session. As mentioned above, all transitions occurred during natural breaks in the lab procedure. I also chose the transitions to equalize the driver experiences as much possible based on difficulty, length, and type of activity.

2.4.3 Groups of Three

Some lab sections contained an odd number of students, necessitating groups of three. None of the pair programming literature discussed groups of three, so there was no precedent for which role the third group member should take. Iconsidered three options for the role of the additional group member: a second driver, a second navigator, and a newly created or hybrid role.

Creating a new role could have upset the balance of the pair programming structure. I also rejected placing two drivers within groups of three. One of the potential benefits of structured pairing was ensuring that all students experience working with all of the instruments and circuit elements within the lab. With only one driver per group, and each student acting as driver a roughly equal amount of time, each student would gain that valuable hands-on experience. If two drivers were allowed, one of the drivers with a dominant personality could potentially do all of the hands-on work while either allowing or forcing the other driver to not participate. Thus, I decided it was best for groups of three to contain one driver and two navigators.

2.5 Structured Pairing Implementation

Professor Loui and I obtained approval from the local Institutional Review Board (University of Illinois IRB #10055) to implement and assess structured pairing within the ECE 110 laboratory during the fall 2009 semester. In this section, I describe the implementation of structured pairing.

2.5.1 Section Selection

In the fall of 2009, there were thirteen lab sections in ECE 110. Seven of the sections operated traditionally; students divided the lab work as they deemed appropriate. The remaining six sections operated under structured pairing. In choosing sections as structured or traditional, I considered three properties of each section that might have influenced student experience: time of day, TA experience, and lecture section instructor. I selected the set of structured sections to be as close as possible, regarding the three listed properties, to the set of traditional sections. The breakdown of structured and traditional sections is shown in Table 2.1.

Table 2.1: Breakdown of Traditional and Structured Sections

Number of …	Structured	Traditional
morning sections	3	2
midday sections	1	1
afternoon sections	2	3
evening sections	0	1*
experienced TAs	6	7
first-time TAs	6	7
sections corresponding to lecturer A	4	3*
sections corresponding to lecturer B	2	5*

* *The evening section combined students of both lecturers*

2.5.2 Informed Consent

During the first lab session, students were informed about the structured pairing research by volunteers who were not involved in the research. Students in both traditional and structured sections were asked to complete consent forms, which are documented in Appendix A, to participate as subjects in the research. All students were informed about structured pairing and the potential benefits and risks. Later, teaching assistants in the structured sections briefed their students on the background and operation of structured pairing from a script I prepared. The complete script is included in Appendix A.

2.5.3 Weekly Operation

At the beginning of each weekly laboratory period, the teaching assistants in structured sections told their students about the transition points—step numbers in the lab procedure when roles should be switched. Whether the students switched or not was mostly left up to the students. The primary job for each teaching assistant was to guide students through the lab. Teaching assistants answered questions, helped students with instruments, and provided demonstrations. These tasks consumed most of their time during the lab period. Ensuring that students followed the structured pairing protocol was secondary.

Some teaching assistants tried to maximize participation. In my two structured sections, my co-teaching assistant and I required students to write the name of the driver at each transition point on their lab reports. I also asked each group to tell me who was acting as the driver whenever they asked for help. These two measures may not have ensured that groups participated in structured pairing, but they did remind the students to participate and should continue during future implementations of structured pairing.

At the end of each lab period, students in all sections were asked to complete brief, informal, anonymous surveys about their lab experience. The survey contained only four multiple choice questions and took about two minutes to complete. A copy of the brief survey is included in Appendix A. I used the brief surveys to keep the teaching assistants and the faculty supervisor informed about the students’ feelings, concerns, and suggestions regarding the lab. I also used the brief surveys to determine how closely students in structured sections were following the structure pairing protocol. Each week, full participation, meaning students switched roles at each designated transition point, ranged from 20 to 25%. Partial participation ranged from 70 to 80%.

2.6 Data Collection

Aside from the post-lab surveys mentioned in Section 2.5.3 and a random selection of student lab reports, which were used for formative purposes only, I collected a variety of quantitative and qualitative data to assess the effectiveness of structured pairing. The quantitative data include voluntary, anonymous, end-of-semester surveys, enrollment data from the College of Engineering, final exam grades, and course grades. The qualitative data include two focus groups, one with structured pairing students and one with traditional section students. I analyze these data in Chapters 3 and 4.

Chapter 3: Results from Quantitative Data

I presented initial quantitative findings, including end-of-semester survey results and final exam grades, in a work-in-progress paper at the 2010 Frontiers in Education (FIE) conference [9]. Here I present all quantitative data, including College of Engineering enrollment data which were not presented in the FIE paper.

3.1 End-of-Semester Surveys

During the final meeting of each lab section, teaching assistants asked students to complete a voluntary, anonymous survey. The survey is presented in Appendix A. The students were notified that their individual responses would remain anonymous and confidential, and that their participation would not affect their course grade.

The date of completion was chosen to ensure maximum participation. Students were required to attend the final meeting in order to receive points for the final project, which accounted for 30% of their lab grade. Placing the survey during the final meeting also allowed the students to experience as much of the course as possible before completing the surveys.

Of the 326 students enrolled in the ECE 110 laboratory, 213 students completed the end-of-semester survey. This number includes 104 students from five of the six structured sections and 109 students from six of the seven traditional sections. Teaching assistants for the sections without data either forgot or were unable to administer the survey due to time constraints.

The survey contained forty items for which students were asked to answer on a five-point integer scale. Participation on each item ranged from 102 to 104 students in structured sections and 104 to 109 students in traditional sections. In many cases, students simply opted not to respond. In a few extreme cases I discarded student responses because they fell outside the range of acceptable answers. For example, one student answered “72, yes, no” on three consecutive questions for which the acceptable responses were -2, -1, 0, 1, or 2.

Since the scale for responses was discontinuous, I used a Mann-Whitney U-test to check for differences between the structured and traditional sections. Of the forty survey items, twenty-four items showed a significant, positive change from the traditional to the structured pairing sections ($p<0.05$). There were no significant negative changes.

The results are shown in Table 3.1. Survey items are displayed under their original section headings in the order in which they were presented on the survey. The mean answer for both structured and traditional section students is presented, with positive changes ($p<0.05$) indicated with an asterisk. For easier comparison, I have normalized the mean item values to the same five-point integer scale, with 1 being very low or negative and 5 being very high or positive, so that values are consistent. For example, item 28 was originally rated on a scale from -2 to 2, with -2 corresponding to “too little work” and 2 corresponding to “too much work.” In Table 3.1, for item 28, the value 1 indicates “too little work” and 5 indicates “too much work.”

Table 3.1: End-of-Semester Survey Data

Item (with original section headings)		**Average Structured Response**	**Average Traditional Response**
Please rate the following items			
1	Confidence in my laboratory skills	3.91*	3.64
2	Confidence in my electrical and computer engineering knowledge	3.91	3.73
3	Confidence my car will complete the final track	3.39	3.28
4	Satisfaction with the lab portion of ECE 110	4.14*	3.57
5	Satisfaction with ECE 110 as a whole	3.85	3.68

Table 3.1: Continued

6	Satisfaction with the ECE program at Illinois in general	4.29*	4.06
Please rate your level of agreement with the following statements			
7	I am pleased with my ECE 110 laboratory experience	4.18*	3.65
8	Electrical engineering is an exciting field	4.07*	3.81
9	Computer engineering is an exciting field	3.89	3.77
10	I am comfortable checking voltages, currents, and resistances using the digital multimeter	4.51	4.33
11	I am comfortable capturing signals using the oscilloscope.	4.00*	3.73
12	I am comfortable reading the frequency, period, and peak-to-peak voltage of a periodic signal using the oscilloscope.	4.12*	3.81
13	I am comfortable setting up a simple circuit using resistors and diodes.	4.36*	4.12
14	I am comfortable designing a circuit using simple logic elements.	4.52*	4.12
15	I am comfortable wiring a circuit using TTL logic gates from an existing design.	4.28	4.08
16	I am comfortable wiring a circuit using TTL logic gates from my own design.	4.23*	3.93
17	I am comfortable debugging a circuit that includes TTL logic gates.	4.27*	3.84
18	I enjoyed working with my lab partner(s).	4.67*	4.42
19	I am comfortable working with a partner or group in a laboratory setting.	4.60	4.43
20	I am comfortable working with a partner or group in a non-laboratory setting.	4.48	4.45
21	I would be willing to work with a partner or group in future engineering laboratories.	4.59*	4.32
22	I participated in lab to the best of my ability.	4.46	4.37
23	I feel like I had an equal part in my group's success.	4.45*	4.15
24	Everyone in my group did their fair share.	4.40*	4.09
25	I am proud of the work I have done in ECE 110 lab.	4.42*	4.19
26	I plan to take more ECE courses beyond what is specifically required by my major.	4.23	4.06
27	I plan to continue my ECE studies (or transfer into ECE)	4.43	4.23
Please rate the following items			
28	Workload in the ECE 110 laboratory	3.19*	3.49
29	Difficulty of the weekly laboratory tasks	3.35*	3.59
30	Difficulty of the final project	3.32*	3.56
Please rate the impact the ECE 110 laboratory has had on the following items			
31	Desire to pursue a degree in engineering	4.25*	3.92
32	Desire to take more ECE courses or major in ECE	4.13*	3.74
33	Confidence in my laboratory abilities	4.20*	3.91

Table 3.1: Continued

34	Confidence in my electrical and computer engineering knowledge	4.16	4.03
35	Confidence in my ability to achieve a degree in engineering	4.26*	3.98
36	Overall engineering knowledge	4.21	4.20
37	Satisfaction with the ECE program at Illinois	4.23	3.97
38	Perception of the ECE 110 course	4.12*	3.67
39	Ability to work in a group in a laboratory setting	4.35	4.27
40	Ability to interact with peers	4.38	4.30

Asterisks denote statistically significant changes: * $p < 0.05$

The survey results seem to support the findings of McDowell et al. [6] regarding student confidence, satisfaction, and persistence. When compared with students in traditional sections, students in structured pairing sections reported significantly greater confidence in laboratory skills, satisfaction with the ECE 110 laboratory but not the course as a whole, and desire and confidence to pursue engineering degrees. Further, students in structured pairing sections perceived that the workload and difficulty of laboratory assignments were lower. Students in structured pairing sections also felt that their laboratory experiences were more positive and equitable.

3.2 Enrollment Data and Course Grades

In January 2010, I obtained ECE 110 final exam grades and ECE 110 course grades of consenting students. In June 2010, I obtained course enrollment for the spring 2010 semester, academic major as of June 30, 2010, gender, ethnicity, and ACT-Math scores of consenting students. I present these data in the following sections.

3.2.1 Comparison of Two Groups

Two-hundred and forty students allowed their academic, enrollment, and demographicdata to be used in this study (including 126 from structured sections and 114 from traditional sections). First I compared the two groups to determine whether they were demographically and academically equivalent. Between the structured and traditional groups, there were no significant differences in the final exam scores, or in the number of minorities, women, students with ACT-Math scores below the median of 34, and students who passed the course with a ‘C’ or better. Thus, the structured and traditional groups can be considered demographically and academically equivalent. Table 3.2 gives a summary of these demographic and academic data.

Table 3.2: Demographic and Academic Data

	Structured (N=126)	Traditional (N=114)
Average final exam score (out of 100)	68.7	68.1
Underrepresented minorities	12 (9.5%)	5 (4.4%)
Women	7 (5.6%)	12 (12%)
Low ACT-Math score	37 (29%)	32 (31%)
Passed with C or better	102 (81%)	89 (86%)

3.2.2 Persistence Results

Like McDowell et al. [6], I analyzed the persistence of students in engineering. In addition to analyzing the data by gender, I also considered two groups of students who are traditionally less likely to persist within engineering majors: underrepresented minorities and students with below-average academic potential (marked by students with ACT-Math scores below the median score of 34).

To determine persistence, I used each student's academic major after six months and the courses they took the semester after completing ECE 110. It is difficult to change colleges or majors in the first year, so I used courses taken to indicate intention. If a student takes further engineering courses, it is likely that student intends to continue in engineering. Additionally, if a student hopes to graduate on time, the student will likely take an engineering course every semester.

I did not obtain students' grades in the electrical and computer engineering courses following ECE 110 because there is no definitive second course in electrical and computer engineering, and none of the courses typically taken directly after ECE 110 (ECE 190, ECE 210, and ECE 290) has a significant electronics laboratory component. Table 3.3 contains all of the persistence data.

At Illinois, freshman engineering students have specified majors, such as electrical, computer, mechanical, or civil engineering. I define an engineering major as a student whose major is within the College of Engineering (including Engineering Physics and Computer Science). I define an engineering course as any course listed within an engineering department or any other science or technical course typically taken by engineering students (such as 200-level physics courses).

Table 3.3: Persistence Data

	Women (N=19)		Minority (N=17)		Low ACT (N=69)		All (N=240)	
	Str.	Trad.	Str.	Trad.	Str.	Trad.	Str.	Trad.
% of students majoring in engineering after 6 months	85.7	91.7	83.3	100	86.5	93.8	88.9	86.8
% of students majoring in engineering after 6 months among those who began ECE 110 as an engineering major	85.7	91.7	83.3	100	78.4	90.6	89.8	90.7
% of students who took another engineering course in the semester following ECE 110	100	83.3	91.7	100	91.9	93.8	93.7	93.0
% of students who took another engineering course in the semester following ECE 110 among those who began ECE 110 as an engineering major	100	83.3	83.3	100	83.8	90.6	93.2	93.5

I had hoped to show stronger persistence among students who participated in structured sections. The end-of-semester survey results showed greater desire to persist among those students in structured sections. Unfortunately the structured group did not outperform the traditional group significantly in any of the persistence measures based on the enrollment data.

The discrepancy between actual persistence (among all students) indicated by the enrollment data and desired persistence (among all students) indicated by the post-semester survey data may be explained by two factors: the high persistence within engineering and the length of time it takes to change majors.

Students typically persist within engineering at a high rate. The enrollment data indicate that about 90% of the ECE 110 students will continue withan engineering major. Because there were very few students involved in this study who decided not to pursue engineering, there was little room for structured sections to outperform traditional sections regarding student persistence within engineering.

The length of time it takes to change majors may have also influenced the discrepancy between actual and desired persistence. I was able to obtain the majors of all consenting ECE 110 students six months—or slightly more than one semester—after they completed the course. I would have obtained the majors of all consenting students after one full year, but as of this writing, less than one year has elapsed since the end of the Fall 2009 semester. Unfortunately, it can take multiple semesters to officially change a major. Even students who decided to change majors while, or shortly after, taking ECE 110 may not have had their majors officially changed. Thus, the six months post-ECE 110 enrollment data are the best available, but they may not accurately portray the intended majors of all students.

I was also unable to find significant differences in persistence for both women and underrepresented minorities. The sample sizes were not large enough due to the small number of women and underrepresented minorities enrolled in ECE 110. McDowell et al., [6], who found pair programming to increase persistence among women in computer science, had a sample size of 51 women.

Chapter 4: Analysis of Qualitative Data

On January 26 and 28, 2010, Professor Loui and I held two focus group interview sessions to gather students' perceptions and comments regarding structured pairing, group work, and their ECE 110 laboratory experiences. The focus groups were open to all students who were enrolled in the ECE 110 laboratory during the fall 2009 semester. A call for focus group participants was sent out via e-mail to all eligible students,and a maximum of twelve spots in each focus group were granted to on a first-come, first-served basis. Due to limited responses, all those who volunteered were allowed to participate. Each student was paid $10 for participation. Copies of the consent form and e-mail solicitation are included in Appendix B.

The January 26 group consisted of ten students from traditional sections and one student who mistakenly came from a structured section but did not mention he was in a structured section until midway through the interview session. The structured student's responses were discarded. The group consisted of nine males and one female. There were six electrical engineering majors, three computer engineering majors, and one engineering mechanics major. Students in this group were given letters A–K in order to distinguish between individual responses and preserve anonymity. Student I was the student whose responses were discarded.

The January 28 group consisted of seven students from structured sections. The group consisted of all male participants. There were four electrical engineering majors and three computer engineering majors. Students in this group were given numbers 1–7.

None of the students in either section were part of the same lab group in ECE 110.

Each focus group session was about ninety minutes in length and consisted of about ten questions. The questions differed slightly between the two groups. The scripted questions were mostly the same, though there were some differences due to the differences in the lab experiences between the traditional and structured groups. Also, different follow-up questions arose due to the divergent paths the interviews took. The original interview protocols and complete lists of questions asked are included in Appendix B.

Once the focus groups were completed, the recorded audio from each was transcribed. Professor Loui and I analyzed these transcripts using grounded theory [10]. First, we independently read through the transcripts and marked them with notes referring to important passages. We then created a list of codes referring to recurring and important themes. We read through the transcripts again and independently marked passages that demonstrated one or more of the codes. We then cross-checked the independent codings at an agreement rate of 95%. From the reconciled transcript coding we searched for any differences in student perceptions, experiences, or attitudes. Since there is little research in this area, we had no a priori expectations for the results.

In the following sections, I present selected quotations from the focus groups and brief discussion of themes of and differences between the structured and traditional focus groups. A quote from Student X, where "X" represents the identifying number or letter given to the student during the focus group, is displayed as follows:

> **Student X (Line number of corresponding transcript)**
> Quotation…

4.1 Division of Labor

In Chapter 2, I mentioned that most, but not all, ECE 110 lab groups divided the laboratory work roughly equally, but that some groups were burdened with free riders or overbearing leaders. Structured pairing attempts to create more equitable partnerships by ensuring the participation of all members of the lab group.During the focus groups, I asked the students to comment on division of labor within their lab groups.

The students in both focus groups claimed a mostly equal division of labor.

> **Student 6 (43)**
> …work was evenly split.
>
> **Student 2 (47)**
> …we split our activities up pretty well.
>
> **Student 1 (79)**
> But in terms of sharing the workload, we both did close to the same amount…
>
> **Student C (101)**
> We pretty much divided work fairly.

Though most of the interviewed students claimed an equal division of labor, we also found free riders and overbearing group leaders.

> **Student 7 (40)**
> …I was behind because he wasn't helping me. And I designed the whole car basically.
>
> **Student J (109)**
> However, when it came to the final design lab, I ended up doing most of the work so there really wasn't much delegation.

4.1.1 Natural Switching

Students in structured sections were asked to follow the structured protocol for the entirety of the semester. Though the teaching assistants tried to enforce the structured pairing protocol, their main duty was to assist students with the course material itself. The students were responsible for adhering to the designated roles and switch points. For the first few labs, students in the structured sections focus group reported that they followed the protocol. They understood the potential benefits of structured pairing and wanted to reap those benefits.

> **Student 5 (75)**
> I would say for the first part of the labs, you know, where a lot of it was learning to work with components and different skills in the lab, we definitely tried to follow that pattern as best we could, mainly because we both wanted to learn the skills that were being learned in the lab.
>
> **Student 2 (78)**
> At the beginning of the term, we attempted to follow all the switching points because, I mean, we understand that it would probably help us learn better in the lab.
>
> **Student 1 (79)**
> I would say that we followed the switching points according to what the TA told us the first three or four labs maybe.

According to the post-lab surveys, 70-80% of students in structured sections claimed to follow structured pairing some or most of the time each week. In addition, most focus group students at least attempted to adhere to the protocol initially. Yet, most of the interviewed students had stopped following the protocol by the middle of the semester. Instead, they adopted a looser method of switching roles that we tentatively dubbed “natural switching.”

As described by the students, natural switching still involved a navigator and a driver, though the duties performed by each student within the roles were less rigidly defined. The main difference between the standard structured pair switching and natural switching is the point in lab at which the role switch occurred. Initially, “switch points” were set at convenient places in the lab procedure based on three factors: to give each student nearly equal time as the driver, to switch roles at section breaks in the lab procedure (as often as possible), and to ensure students did not go too long without switching roles (McDowell’s students switched every twenty minutes [6]). The students who adopted natural switching disregarded these specified switch points and decided to switch roles at their own “natural” points during the lab session.

Student 3 (77)
In my group, we did not really follow the outlined switching points, but we did find that there were some natural ones that occurred sometimes right in accordance with where the lab said to switch.

Student 2 (78)
We discovered that some of the labs took quite a long time, and we kind of weren’t learning everything we should be because we weren’t finishing the labs. We ended up, like Student 3 said, there were like natural switching points. So we kind of gravitated towards our roles. So one of us would be wiring, the other person would be describing like how this specific wiring is supposed to be done, like what the concepts are behind it. Usually that person, whoever was wiring, would stay with that until we switched to a completely different concept.

Student 5 (112)
...a driver-navigator I guess roles did emerge eventually. When one person had the hands-on wiring or so, the other partner obviously was watching, checking to make sure it’s right or makes sense logically. So I think even if you didn’t even call it the “driver-navigator,” it tended to… emerge in a lot of cases. At least with my lab partner.

4.1.2 Time Concerns

Especially towards the end of the semester, students became increasingly concerned with limited laboratory time. Students were given three hours to complete each weekly lab, and they could attend optional extra sections during the three weeks they were given to complete their final projects. Still, many students were unable to complete the more involved lab assignments on time, and the open-ended design project allowed for unlimited hours of work. As a result of the perceived time shortage, students tended to work in a manner they perceived as the most time-efficient.

> **Student 2 (77)**
> We discovered that some of the labs took quite a long time, and we… weren't learning everything we should be because we weren't finishing the labs.
>
> **Student 3 (88)**
> I felt like time was a really big constraint as you get further into the semester.
>
> **Student 5 (75)**
> But when it got towards… the actual project and… there was visibly time ticking down, we needed to get things done by deadline. We… started dropping the whole pattern [of structured pairing] and just [adopted] the distribution [of labor] that would… suit us best and be most efficient.
>
> **Student K (104)**
> During the first guided labs… I ended up doing pretty much all the work because I was the one who was fastest at it, the most motivated.

Although students from traditional and structured sections demonstrated mostly equal division of labor and time concerns, they divided the work differently. Students in traditional sections divided the work unsystematically, by convenience: whoever was closest to the target equipment, whoever was "in the mood," or whoever got the inspiration carried out the task.

> **Student F (105)**
> It was just, whoever was closest to this cable, go and get it. Whoever is closest to the button, push it. And… during the final design challenge… if you have an idea how to make this circuit work, you go and try it.

> **Student G (106)**
> It was kind of like what they did [referring to Student F]. Whoever was… working on that side of the project, or whoever felt more motivated would go ahead and do that task.

> **Student E (103)**
> It really depended on the mood of my partner and how we would divide the labor. If… hewanted to [implement] the logic, I would [connect] the circuits, and the [next] day we'd just go vice versa.

The unsystematic behavior of the traditional section students starkly differed from the behavior of students in the structured sections, who mostly divided labor by specialization. By the end of the semester, most of the structured groups had formed a good working relationship. When time was a factor, they split up the work based on who was most adept at each task in order to complete the project quickly.

> **Student 5 (99)**
> The only major reason [structured pairing] was really hard to implement towards the end of the semester was that we found it just quicker to specialize… It's a lot more efficient as far as time, which is definitely a scarce resource in lab.

> **Student 6 (104)**
> …and we did, at the end, specialize so that we would finish the labs quicker and get done.

> **Student 2 (110)**
> We usually operated as specialization [at the end of the semester]. That's the way that you operate quickest, by specializing what you do best.

4.2 Teamwork and Mutual Success

In Section 4.1.2, I introduced the idea of specialization in structured groups. Specialization seems to be part of an overall trend of greater teamwork within the structured sections. While students from both sections placed great importance on completing assignments and earning good grades, students in structured sections demonstrated a greater emphasis on teamwork and success of their partners as well.

Two statements in particular show this notion of teamwork. When a structured group encountered a lab task that one student was familiar with but the other was not, the group tended to allow the inexperienced student to take the lead while the more experienced student guided him through it.

> **Student 3 (77)**
> It tended to be more of a situation if someone had more of an experience with it, they'd back off or help the other person because there was a lot of [confusion] with so many different topics. There [were] a lot of situations where one person actually had a really good grasp on it, but one of the other two of us did not. So there was a lot of helping each other…
>
> **Student 6 (81)**
> …there were times when one of us would know whatever material was being presented better than the other person. In that case, that person would be the [navigator] and help the other person kind of navigate his way through the lab and try to learn for himself.
>
> **Student 1 (34)**
> I was lucky to really get a good partner…he sort of knows more about [logic] and wiring stuff more than I do. And working with him actually taught me how to do stuff better and how to learn quicker.

Unlike structured pairing students, traditional section students did not mention helping partners through new tasks. Instead, they emphasized completion and efficiency. In only one instance did a traditional student help his partner learn the material, but this was done outside the lab (while working on the final project) and was done so almost begrudgingly.

> **Student J (95)**
> Thanksgiving break was spent trying to like reteach the 110 concepts over the phone with my partner. So that was a breakdown the whole design I'd come up with.

4.3 Seeking Help

In the lab, partners are the primary resource for help. Students are paired or grouped so they have someone on whom to rely if they are unsure about an engineering concept or how to proceed with a laboratory task. In ECE 110, as in most labs, teaching assistants are also present to provide further help, to answer more difficult questions or aid a group when all members are unsure what to do. However, lab partners do not have all the answers, and teaching assistants are often busy helping other students. Assistance in the laboratory should extend beyond other members of the group and teaching assistants.

In ECE 110, as in many laboratory courses, there is not just one group of students working at a time. Each ECE 110 laboratory section consists of twenty to twenty-eight students organized into ten to fourteen groups. Thus, each student could receive help from approximately twenty other students.

Seeking help from another student or another group is not a completely obvious thought for most students, though. Traditionally, engineering is a competitive discipline due to its military roots [11]. In school, students compete with one another for better grades [12]. Later they will compete for jobs, and later still for industrial and scientific breakthroughs. It is sometimes difficult to help or to seek help from a "competitor." Students in structured sections, at least, did.

Students identified two circumstancesthat spurred intergroup cooperation. The first was a free-riding lab partner. In the absence of a helpful lab partner, students turned to other groups for assistance. In the case of Student 7, a strong relationship formed with a student from an adjacent lab group. Not only did the two students help each other during the regularly scheduled lab sessions, they met and worked together during extra lab sessions.

> **Student 7 (65)**
> But there was one guy from the team that worked right next to us that I grew really close with because he'd show up, he was very hard-working. He'd show up to all the extra lab sessions and that's how I kept meeting him. And with him, we would talk a lot about our designs, why some things weren't working. And that was a very good experience. I grew really close with him and we'd just work out problems, both of us seeing like, he was better at the actual wiring and I'd try to simplify the logic so the circuit wasn't too messy. And things like that. And I learned a lot from him.

Student 7 and the other student formed a surrogate lab pair, because neither of their own partners were very helpful. This partnership was so strong that Student 7 felt proud when his surrogate partner's car completed a perfect run on the final track. He had put so much work in on the surrogate partner's car that he almost considered it his own.

> **Student 7 (69)**
> When I worked with him on the actual lab sessions and things like that, I helped him troubleshoot his design many times because he had a similar case as mine where his lab partner didn't really mess with the circuit. He didn't add much. So

> we grew really close together even though we implemented our own different designs, we disagreed on some things, but… when he got the perfect run he was really happy because he got cheered and got his picture taken and everything. I felt really good also even though it wasn't my car; it wasn't my design. I felt like I had, it felt really good.

Student 4 also found help in an adjacent lab group, though his experience differed from that of Student 7. Unlike Student 7, who naturally came into his surrogate partnership, Student 4 was forced to work with another lab group due to the absence of his partner.

> **Student 4 (66)**
> …my lab mate broke his thumb toward the middle of the lab somewhere. So I… teamed up with the neighboring two guys as well.

There was certainly amicability and the passing of ideas between Student 4 and his neighboring group, but there was no evidence that the relationship was as strong as that of Student 7 and his outside help. He had simply worked with them for a small number of lab sessions and in that time they had contributed more towards Student 4's car than Student 4's own partner had. There was no evidence of "sharing in the success" as there was in Student 7's statement.

> **Student 4 (66)**
> I got along very well with them and one of them was fast and, you know, aggressive with the lab and so, we just matched each other. So we, at the end of the car actually came together, if I had to work up a design and everything, it was more the other person's contribution than my own lab mate.

The second circumstance that spurred intergroup cooperation involved previous acquaintance. Groups communicated more freely with other groups if members of both groups were already friends. With communications open, students in structured sections were comfortable seeking help from other groups. As in the cases of Students 4 and 7, the helper groups were seated adjacent to the groups seeking assistance.

> **Student 2 (67)**
> My lab partner was really close friends with the group next to us, so with that, we ended up troubleshooting each other's designs several times and helping each other on the final car.
>
> **Student 5 (68)**
> My lab partner was friends with the group next to her. [When] there were some difficult concepts … we would bounce ideas off each other as to what would be going right or going wrong and trying to come to a solution and it benefited both [of] our groups.

Students 2 and 5 were drawn into intergroup cooperation not by a strong need for help as were Students 4 and 7, but because they saw the benefit in hearing outside opinions. There was not a sense of competition but mutual success. Student 2's group went as far as to share troubleshooting of the final design. The mutually beneficial relationship broke down at the end as time became a concern and Student 2's group fell behind on their design work, but the spirit of helpfulness remained.

> **Student 2 (67)**
> But ultimately, we were further ahead of them at the end, and so they really couldn't help us too much. And we were too far behind in implementing what we wanted to do to help them too much. So that kind of fell apart as the final car ended up, the final week they really couldn't help that much and we really couldn't help them. But prior to that, they really helped us and we really helped them understand the things of the lab and how to make the logic and such.

Students from traditional sections discussed neither intergroup cooperation nor surrogate partnerships. As I mentioned in Section 4.1, Students J and H experienced free riders, and thus had the opportunity to seek outside help as did Students 4 and 7. But, neither traditional student seized that opportunity. Instead, Student J focused on working on his design alone and then on tutoring his partner in basic course concepts towards the end of the semester.

> **Student J (95)**
> Thanksgiving break was spent trying to like reteach the 110 concepts over the phone with my partner. So, that was a breakdown the whole design I'd come up with.

Student J did seek advice from his teaching assistant regarding his partner, whose lack of helpfulness was a product of low confidence in his knowledge of course material. The teaching assistant's advice did not encourage Student J to seek help in members of other lab groups.

> **Student J (95)**
> At first… I asked the ECE 110 TA for advice … because my partner had a lack of confidence in … the concepts of the entire ECE 110 and applications, concepts. And so, advice was pretty much given that be patient and work through and this is something you will deal with in the real world.

Student H took a less active approach with his free rider. He simply completed the group's work while his partner remained uninterested and uninvolved.

> **Student H (97)**
> There wasn't really a conflict resolution because my lab partner would often leave an hour early and I'm not sure if he really cared about the outcome of the lab. So it really just came down to me to finish.

The single instance of seeking help from another lab group among the traditional section students came from Student H’s lab partner, who simply communicated with another group to obtain answers for his weekly lab reports. Seeking help only to get answers contrasts sharply with the mutual help among members of separate groups that is evident among the students in structured sections.

> **Student H (97)**
> On the two occasions that he actually stayed, there wasn’t so much resolution as I finished and he asked his friends for their answers.

Students also had access to, but did not mention, many other resources: interaction with other students and instructors through ECE 110 web boards, face-to-face interaction with students in different sections and course instructors, and assistance from additional teaching assistants during extra sessions.

Student G spoke briefly and vaguely about his partner searching the Internet for answers, but his response was the only mention in either focus group of help outside of lab partners, adjacent lab groups, or teaching assistants.

> **Student G (106)**
> …he would come into the lab and say, “I was looking at this on the Internet”…

4.4 Why Groups Stopped Switching

Though five of the seven students in the structured sections focus groupgenuinely attempted to follow the structured pairing protocol, none of the seven students followed the protocol for the entire semester. Some of the students dropped the rigidly defined switch points for a more natural switching scheme whereby they switched roles at places in the lab procedure that were more convenient for them. Other students simply ignored the roles altogether.

An educational technique cannot be useful if students are unwilling to follow it. It is important to consider why students stopped switching so that future attempts at structured pairing can be altered to ensure maximum participation.

I first discussed time limits in the Section 4.1. Students from both traditional and structured sections worried about finishing assignments on time. The students began to alter their work habits to a way they deemed more time-efficient. Students from structured sections often discontinued the outlined protocol for natural switching.

> **Student 5 (75)**
> …we needed to get things done by [the] deadline. We…started dropping the whole pattern and just working with the distribution that would… suit us best and be the most efficient.
>
> **Student 2 (78)**
> We discovered that some of the labs took quite a long time, and we… weren't learning everything we should be because we weren't finishing the labs. We ended up, like Student 3 said, [with] natural switching points…And we didn't really have that much time to waste, especially with the final car design, because by then, it was kind of a dash to the finish and we didn't have time for protocol.

Other students found structured pairing to be inconvenient. These students seemed to believe structured pairing was meant only for groups who did not get along or did not work well together naturally. Since they were comfortable with their partners, they felt they were not obligated to follow the protocol. Instead, they developed working processes that were more convenient for their individual groups.

> **Student 1 (79)**
> I would say that we followed the switching points according to what the TA told us the first three or four labs maybe. Then after that… we got to know each other better and… we just both did it together. It came down to just like when someone, we were both writing something on our labs, it was just who finished first would touch the car and just work on it.

> **Student 6 (72)**
> We tried following it a couple of times, but for the most part, since we worked well together, we didn't take on the positions.

A unique circumstance occurred in Student 3's group. Like some of the other groups, they turned to natural switching. This group did not ignore the outlined protocol out of inconvenience or a concern for time. They switched roles in order for inexperienced group members to obtain more hands-on experience with unfamiliar tasks. The goal was to ensure every group member received the maximum benefit of the course.

> **Student 3 (77)**
> It tended to be more of a situation if someone had more of an experience with it, they'd back off or help the other person because there was a lot of, with so many different topics, there [were] a lot of situations where one person actually had a really good grasp on it. But one of the other two of us did not. So there was a lot of helping each other.

Student 3's group followed the "inexperienced person leads" technique throughout the weekly labs. During the final project, their technique was the complete opposite. Instead of the inexperienced person leading, acting as the driver, whoever had the best grasp of the current concept or whoever had an idea to implement would act as the group's leader.

> **Student 3 (80)**
> I felt that…if there was a situation where maybe one person had an idea for logic to implement, that they would end up usually taking the lead for the foreseeable future as we [implemented and] tested it…And it just worked out nicely that we all alternated ideas and our contributions to the car.

Student 3's group was close to the ideal for a lab group in ECE 110 or a similarly structured class. During the first ten weeks, the goal for the course was for students to learn the material and gain experience, which is what Student 3's group focused on. During the final project over the final three weeks, the focus of the course changed to a deliverable. The goal was to design and build the best possible autonomous vehicle. Student 3's group shifted its focus from learning laboratory skills to working towards the best design. During this final phase, each member of the group contributed equally, presumably because they had spent the first ten weeks learning and not letting any member fall behind the others.

Unfortunately, even in structured sections, students did not always work together. Two students reported that their groups stopped switching, or ignored the roles altogether, because one member refused to participate.

> **Student 7 (71)**
> In the beginning, well the TA specified the whole alternating, like the driver and the other roles. And we tried to follow that. But me and my lab partner just, he just kept repeatedly telling me, "No, no, you do it. You do it." I mean, it's a timed lab and some of the earlier labs took the whole time. And sometimes we didn't even finish. So, for the sake of time, I had to put up with him and just do it myself.

> **Student 4 (32)**
> My lab partner pretty much let me do everything. So it was more like I was dominating and I was the one who was doing all of the individual work.

Student 4 (76)
I was pretty much the [driver] for all of the labs…We didn’t follow it at all. It was completely one-sided.

4.5 The Ideal Lab Partner (and What’s Missing)

We asked students in both focus groups to describe their ideal lab partner. According to Loui [13], traits of a lab partner can be grouped into four categories: interpersonal skills, work ethic, technical experience/skill, and moral standards. Since students placed an emphasis on completing assignments and earning good grades, I initially expected that students would value partners who would help them achieve these goals: partners with strong technical experience/skill and work ethic.

When describing the ideal lab partner, students in both traditional and structured sections did place emphasis on work ethic and effort.

Student H (163)
…whether or not they… can put out exactly 50%, or whether they even do more than you. I feel like that’s less important than whether or not they actually try.

Student 1 (115)
I feel like he should be someone who I guess is motivated and who is willing to help and work.

Student 6 (122)
I think you definitely need somebody who’s hard-working…

Student 2 (118)
…showing a good work ethic and keeping working until they achieve their goal.

Students in both sections also desired partners with strong interpersonal skills. Primarily, they were interested in communication and respectfulness.

> **Student B (165)**
> A good lab partner would be easy to communicate [with].
>
> **Student 7 (127)**
> Definitely also someone with good communication.
>
> **Student G (160)**
> But a lot of times, a conflict I would see in my lab section; one student would have an idea of employing a certain design and another would have a different idea of a different type of design and… they'd have a hard time resolving which design to use…if you had a good partner, you were able to work through and maybe try each person's design.
>
> **Student 3 (119)**
> …someone who's personable and can communicate well and who you can sustain a mutual respect with.

Despite initial expectations, no student in either section listed technical experience/skill among the attributes of their ideal lab partner. Perhaps students valued learning over good grades more than they let on. After all, grades in the ECE 110 laboratory tend to be uniformly high, so students may not have been concerned with earning a good grade. Alternatively, students may have expected other students to come into lab with limited experience and skill because ECE 110 is an introductory course.

Students also left out moral standards among traits of an ideal partner. Since most students are moral and ethical, they assume other students will be moral and ethical as well. Moral standards may be taken for granted in a lab partner, much like interest in engineering among students who are enrolled in an engineering course.

One student did mention possible unethical behavior by his partner in response to a question regarding conflicts.

> **Student 4 (62)**
> I had only one conflict with my lab mate. And that was enough to sour everything. It was on the last day itself. And like I just said, he brought in the board thinking that he'd made all the right modifications and the car would work perfectly now that perfect logic was on it. And when we put on the car, it wouldn't run at all. And I asked him, I asked him about ten thousand times to look at his design to figure out what was wrong because he changed my logic and my design completely. And he had no idea and I still don't know whether he did something unethical with that, or if it was his own design at all. But we had a big fight and then he basically just begged me, "Look, you know, whatever we get, you know, just pull apart this car and do it all over again. We have one and a half hour remaining, just do something with it."

Though ideal traits described by both groups were limited to work ethic and interpersonal skills, traits described by structured pairing students were more refined than those of traditional section students. Traditional section students limited their responses to "communication" and "respect."Structured pairing students valued partners who pushed them and the group to do their best work.

Students 3, 6, and 7 valued partners who were assertive and provided constructive criticism.

> **Student 3 (126)**
> Someone who is fairly aggressive and would be quick to point out some deficiencies but not be mean about it.
>
> **Student 6 (122)**
> …and who pushes you…
>
> **Student 7 (123)**
> I want someone that can give a good constructive criticism…

Students 1, 2, and 5 valued partners who were attentive, goal-focused, and had positive expectations.

Student 1 (115)
We would wire it and like if someone was wiring it, the other person wouldn't just be standing around like just on his cell phone. He would be looking at the car, looking at the other person wiring it and making sure he's doing it right.

Student 2 (125)
I would like a partner who would say, "Well this isn't going to work, how do you think we can improve it?"

Student 5 (121)
And then there's also a responsibility to make sure that your lab partner is maintaining that sort of same level and that you would expect the same out of them as they should expect out of you.

Though the prompt was not for the students to describe the ideal navigator, they have done exactly that. The ideal navigator should be goal-focused, constructively critical, assertive, attentive, monitoring, and harbor positive expectations. The ideal navigator should also be a facilitator. He or she should check for understanding, do complementary work, and help his or her partner to learn;all of these are qualities thestructured pairing students desired in an ideal partner.

Student 1 (115)
And by "work" I mean like help read the lab, make sure I understand.

Student 7 (123)
I want…someone that complements you, not someone that … leads you to more individualistic or an approach to designing you project. Instead of being two parallel tracks, you designing your thing and your partner designing his thing, I would like someone who can complement you, someone who can work with you.

Student 2 (118)
I suppose that my ideal partner to help me learn the most, get the most out of the material, would be a partner who would help me follow directions, who would have a clear idea in mind…

The ideal navigator does not need strong technical experience to be successful. If students truly consider the ideal navigator to also be the ideal partner, it would explain why they did not list strong technical experience as a desired trait of the ideal partner.

4.6 Relationships over Time

Ideally, students in a lab group would work together amicably from the beginning to the end of the semester. They would work efficiently, resolve conflicts quickly and fairly, and overcome challenges as a team. Unfortunately, lab groups do not always function ideally. In many cases, relationships among members of lab groups change both positively and negatively over the course of a semester. In some cases, group members never cooperate at all. Students from the focus groups described three categories of group relationships: amicable, uncooperative, and changing.

There were students in both sections who worked well with their partners from start to finish.

Student 6 (43)
My lab partner and I got along really well. We also corresponded via email. We sent each other designs for the final car, helped on the final report. So work was evenly split, [we] got along well. It was a good experience working with him.

Student 5 (44)
Very similar to Student 6, me and my partner got along pretty well. We both put equal effort, both in and outside of the lab when it came down to the wire later on. So I guess it was a good pairing.

Student 2 (47)
Me and my lab partner got together pretty well. It may have helped [that] we were partners on the [group research project for the lecture portion of ECE 110] as well. So we were able to discuss our research activities and our lab activities like during those different times. Yeah, we both put forth our best effort. We showed up on time, which was different in the rest of my RA people. So he was a very good partner to work with. He always did what he said he would and we split our activities up pretty well.

Student C (84)
We got along very well and we are both responsible, so we complete[d] the project together.

Student F (88)
Me and my partner got along well. We didn't really have much of a relationship outside of class. I would say we had a business relationship. But we got along. We didn't do much out of class, but in class we got the job done and did our lab project.

Some students enjoyed their working relationships so well that they became friends outside the lab too.

Student 1 (48)
I got along really well with my lab partner. We became good friends throughout the semester.

Student A (82)
I got along pretty nicely with my partner…In the beginning we were just doing lab work together, but then we would study for the class together and have dinner and stuff, so we became friends.

Student B (83)
I got along with my partner really well, and now we're actually really good friends.

Student G (90)
I got along real well with my lab partner. We still study together. He lives in my dorm so that worked out well.

Students who worked well with their partners provided little information regarding why they were successful. Most students communicated some variation of “we got along well” and then left the issue alone. Students 2, 5, and 6 implied that dividing the lab work evenly and giving equal effort may have aided in some groups’ success. Student 2 also provided evidence that a previous relationship may contribute to a group’s success. In addition, Student 2 noted that a common enemy—in this case a piece of hardware—may help groups work well together by eliminating conflicts between group members.

> **Student 2 (67)**
> The major reason why me and my partner didn’t really have many disagreements was because our major conflict was more with the hardware; it did not agree with us at all.

Though most students in both focus groups were members of successful lab groups, Student 7 was part of a completely dysfunctional group.

> **Student 7 (42)**
> I didn’t get along with my lab partner. I tried to get him into it. I tried to get him to help me. But at every lab it was the same thing; he would just take his laptop and chat with his girlfriend. It was pretty bad.
>
> **Student 7 (40)**
> He gave up on day one. He saw the oscilloscope and said, “Whoa, no, that’s it.”

Just as groups did and did not cooperate for the entire semester, many groups experienced changing relationships throughout the course of the semester. Two factors influenced the change significantly: gaining or losing group members and working on the final design project.

When a group has achieved equilibrium, adding or subtracting from the group can disrupt the group dynamic. Students H and K are examples. In Student H's situation, one member of his group of three left midway through the semester. After that, his relationship with the remaining group member deteriorated. In Student K's situation, an outsider joined the group he had formed with someone he got along with. At first, the group struggled.

> **Student H (79)**
> Actually like for the first four of five labs, I used to have a group of three and then it dropped off. It really does vary, like depend on the people because in the initial group of three, the third person kind of kept the second person in line. But when he left, I couldn't keep him in line, so it ended up me shouldering most of the burden.
>
> **Student H (91)**
> After the third person left, it started going sour. It really just ended because, for the final design project, I got sick and he took everything that I did and I had to redo the entire final design project in four days. I got [mad] at him after that.
>
> **Student K (87)**
> The first labs I moved around a little between … several different partners and… didn't like any of them that much except for one. So, well, when we were supposed to choose final partners for the design project, I fortunately was able to choose him. But then there was… another guy in our lab section who… couldn't find a partner, so he came in with us. He… didn't do a lot of work for a lot of the lab periods and I didn't get along that well with him until pretty near the end when he started actually doing some of the work.

The last three weeks of lab were dedicated to a single purpose: the final design project. Instead of following detailed lab instructions and answering simple numerical and short answer questions, students designed their own complicated circuit and wrote a multi-page report. Their scores on the final project determined 30% of their final lab grade. In some cases, the stress of these final weeks spurred a change in group relationships. For Student 4, the change was detrimental.

Student 4 (45)
My relation with my lab partner was professional since the beginning, but towards the end, our relationship deteriorated because when we had to submit the final project and run the car for the final design, then like it was all my design…I had my complete individual thing over there, but unfortunately, I couldn't implement the parts with modulator properly. So he wasn't satisfied with that and he wanted it more because the sharp, 90 degree corners were not turning. So we had an agreement…he would go and take the car home and he would do something with it on his own. And he didn't do that. When he brought the car, he messed up my entire design. So it got really bad.

Student 4's relationship with his partner was similar to that of Student 7 and his partner because neither had a helpful partner. Student 4 differed from Student 7 because he was happy to do the work himself, while Student 7 desired a helpful lab partner. Student 4's acceptance of an unhelpful partner early on may have led to his disappointment in his partner when he truly needed the partner's help during the final project. Student 7 was less disappointed during the final project because he had learned to seek help elsewhere during the weekly labs.

Unlike Student 4's experience, the final project affected Student K's group in a positive manner.

Student K (87)
[My new lab partner] was the one who didn't do a lot of work for a lot of the lab periods and I didn't get along that well with him until pretty near the end when he started actually doing some of the work. So I think by the end we were working pretty well together though it was a long way.

Student 3's group functioned well to begin with. During the weekly labs, he was friendly with one of his partners and was at least civil towards his other partner. The urgency and importance of the final project caused Student 3 to take charge. Because the group had shared equal responsibility during the weekly labs, Student 3 was aware that taking a leadership role may have caused some strain between him and his second partner, but he took the role to help his group finish the project.

> **Student 3 (46)**
> My relationship with my lab partners was good. With one of them, we became pretty good friends. We studied together for the entire class and if we ever had any questions … we'd always go to each other. For my other lab partner, our personalities didn't get along well, but we still had a very fine relationship. There was no animosity ever. The one issue was that I felt that as we were getting closer and closer to the end, that there was a need to really drive the group. It's not as if people were being like against working or something, they just had no motivation to get up and do it. So in that sense, I really had to … take on sort of a leadership role and not like do everything, but just make sure, and keeping everyone on task. Which was somewhat annoying and I'm sure it didn't help the friendship develop at all. But all in all, I think it was a fine relationship between the three of us. There was never any real animosity.

4.7 Student Suggestions for Structured Pairing

Students in the structured focus group previously described their structured pairing experiences including how often they followed the navigator and driver roles, how often they switched roles at designated switch points, and why they stopped switching. Five of the seven students either ignored structured pairing after the first few weeks or adopted their own version of it. Two students ignored structured pairing altogether. Towards the end of the session, I asked the students to suggest improvements to structured pairing.

Students generally favored structured pairing. Even though the students did not always rigidly follow structured pairing during the semester, they believed it to be a worthy educational technique.

Student 7 (132)
I have mentioned throughout that I like the concept because it meant a more dependable partner.

Student 6 (133)
I think [structured pairing is] a good idea and I think [structured pairing] should probably continue on in the following years.

Student 5 (134)
I don't think I would change too much about it.

Student 3 (136)
I think that the idea, the concept of structured pairing would be wonderful as an ideal.

Student 1 (138)
The idea of structured pairing…I feel like it's a really good thing to do and have.

As with most new educational techniques, the first implementation of structured pairing had its flaws. Most of the students' comments focused on improving the implementation rather than the principles and composition of structured pairing. Students have previously described time constraints on the lab sessions and unnatural switch points as reasons for adopting alternate techniques such as specialization and natural switching. Students 4 and 2 repeated these concerns.

Student 4 (135)
Towards the latter half of the [semester], there are too many time constraints.

Student 2 (137)
Sometimes it seemed like the [switch points] were just arbitrarily picked just to switch for the sake of switch. Maybe if there were fewer switches per lab, just make them consistently.

Students 2, 3, 4, and 6 had identified confusion regarding the roles prior to being asked for suggestions for improvement.

> **Student 3 (97)**
> I don't know if our group or even people around us fully understood exactly what being the driver or being the navigator meant.
>
> **Student 4 (98)**
> I thing part of the problem was with the definitions of both the roles. We didn't exactly realize what the driver was supposed to do and even I myself used it interchangeably with what the navigator was supposed to do.
>
> **Student 6 (100)**
> I agree with Student 4 in saying that the role of driver wasn't really well defined.
>
> **Student 2 (110)**
> Since they're very close in meaning in the English language [it was] awkward trying to decide is one person supposed to be sitting back and telling the other person what to do or is the other person supposed to be sitting back, analyzing the circuitry while the other person is actually implementing it…

Students 3, 4, and 6 reiterated their concerns when asked for suggestions. Students 3 and 6 called for more clearly defined roles while Students 3 and 4 suggested changing the names of the roles to eliminate confusion.

We may have taken for granted that students understood a clear difference between a driver and a navigator. The McDowell study of pair programming took place at University of California, Santa Cruz, where most of the subjects were California natives and had much previous experience driving cars. At Illinois, few freshmen and sophomores drive cars. In addition, many of the subjects in our study were international students who may have had little experience driving cars during high school. Perhaps "driver" makes more sense in communities in which teenagers drive cars more frequently.

Student 6 (133)
Maybe define the roles a little better.

Student 4 (135)
I feel that names often give away definitions…So we need better names for both those roles which would make it clearer even to the person what is meant to be done.

Student 3 (136)
I think that the roles need to be more defined, the name changes, are all good ideas.

Although they did not follow the structured pairing protocol themselves, all of the students expressed the importance of getting students to follow the structured pairing protocol as strictly as possible for at least the first few weeks. Students 4 and 7 suggested enforcing the policy more rigidly by placing more responsibility on the teaching assistants to make sure students are switching properly and creating a system of greater accountability for the students.

Student 7 (132)
… I know how those TA's were busy all the time just asking, solving all the teams' problems. But in an ideal world, be some sort of checks and balances. Doesn't have to be too complex, kind of like in the physics lab we had the little check boxes and then TA just asked you to explain what you did and why it worked and you wrote it down in the thing at least forces the other people in the team to explain it and their words also.

Student 4 (135)
So in the beginning at least, there should be some sort of check and balance but not towards the later after five labs maybe.

Student 7's suggestion refers to freshman-level physics labs for engineering and science majors. In these courses, students check boxes next to statements in their lab procedures to certify that they completed certain tasks or understand certain concepts. The check boxes remind the students of what they should be doing in order to keep them on track. Some ECE 110 teaching assistants implemented a similar system: they had students mark on their lab reports who became the driver at each transition point.

At the end of each physics lab session, students are also individually quizzed to ensure they understand the important concepts of and adequately participated in each lab. Student 7 recommends a similar procedure, though he did not describe the procedure in detail.

Students 1, 2, and 3 suggested that students be strongly encouraged to follow the protocol for at least the first few labs. The students believe that lab students be taught the importance and potential benefits of structured pairingearly on in lab.

> **Student 3 (136)**
> But I really think that the biggest thing is to have the students themselves buy into the idea, to buy into the concept whole-heartedly. I think that a lot of ideas would work wonderfully if everyone buys in. So I think that might be one of the most important aspect is to clearly state to all future students that this is the idea we want to propose, it will help. And you make sure that they understand that having a structured pairing will be beneficial in the long run. And I think if they understand that, they'll be more apt to take hold of it from the get go and you'll see positive results from there on.
>
> **Student 2 (137)**
> Like Student 3 mentioned, make sure everyone understands this will make them learn better and it will make their partners be more active in the partner relationship, I guess. And overall, everyone will be helped by it. Just make sure everyone buys into it and point out that it's not just some social experiment being done in your class.
>
> **Student 1 (139)**
> Try to actually implement it like the first couple labs, like the ones that are not that long and not that hard to finish on time so that the students themselves will see that, ok, they actually learned by switching and that they get through labs quicker and see the benefits of it, so that they know it's a good thing. And after, if it goes on, if students do it at the beginning and if they see it's beneficial, then they're gonna do it by themselves whether or not you have a guideline for it.

Above, Student 3 mentioned that structured pairing would be beneficial in the long run. Recall that Student 3 was part of a group that worked well together during the final project because each member had developed necessary skills over the first ten weeks of laboratory. Student 3 understood that structured pairing provides guaranteed hands-on lab experience to each student, thus producing more competent partners at the end of the semester. Students J and H in the traditional sections understood this concept as well.

> **Student J (131)**
> Yes [structured pairing] would take some patience on the person who learns the material [faster]. However, that patience will pay off when it comes to the final design project. You have a partner now.
>
> **Student H (132)**
> I fully agree…For groups that work well together, you're not really compromising anything. You're still going to have that chemistry and work well together, even if, I mean, but for those groups that don't necessarily work as well together, like you said, you're giving up a little bit of our time. I'm sure if my partner understood stuff instead of leaving an hour early, he might actually have been able to contribute to the final project.

As stated in Chapter 2, the teaching assistants were given a script to read to the students at the beginning of the semester. The script is included in Appendix A. The TAs briefly described the potential benefits of structured pairing—increased confidence, satisfaction, and persistence within engineering—and encouraged the students to participate as best they could. Clearly not all students were made aware of or understood these potential benefits. Perhaps these students regretted not following structured pairing and wished that they had been more strongly encouraged early on. Student 2's comment about the "social experiment" hints that some students may have doubted the efficacy of the structured pairing technique and the credibility of the TA.

All of the students' suggestions should be considered for future implementations of structured pairing.

Chapter 5: Discussion

In order to assess the effectiveness of structured pairing, I collected both quantitative and qualitative data. I administered two surveys: a forty-item end-of-semester survey to assess confidence, satisfaction, and opinions regarding teamwork, laboratories, and engineering education; and short post-lab surveys each week for formative assessment. I used enrollment data including past and current majors and courses taken after ECE 110 to determine persistence. I collected, but did not analyze, student lab reports to ascertain differences in student work. I also conducted focus groups to gauge students' opinions, feelings, and concerns regarding structured pairing, the ECE 110 laboratory, and the engineering program at Illinois. All quantitative differences were statistically significant at the $p < 0.05$ level.

5.1 Confidence, Satisfaction, and Persistence

McDowell et al. [6] concluded that pair programming improves student confidence, satisfaction, and persistence within computer science. McDowell et al. also found that pair programming improved persistence among women in computer science. I found structured pairing to improve student confidence and satisfaction, but persistence results were less conclusive.

5.1.1 Confidence

According to results of the end-of-semester survey (Table 3.1), students in structured sections were significantly more confident in their laboratory skills than were students in traditional sections. Structured pairing students also believed the ECE 110 laboratory had a more positive impact on their confidence in laboratory abilities and ability to achieve a degree in engineering. Structured pairing students were as confident as traditional section students in their electrical and computer engineering knowledge and that their car would complete the final track, but they did not believe the ECE 110 lab had a more positive impact on their electrical and computer engineering knowledge than did traditional section students.

5.1.2 Satisfaction

According to the end-of-semester survey, students in structured sections were more satisfied with the lab portion of ECE 110 and the ECE program at Illinois in general than were students in traditional sections. Structured pairing did not have a significant impact on student satisfaction with the ECE 110 course as a whole.

5.1.3 Persistence

Based on the end-of-semester survey, persistence results were mixed. There was no significant difference in the desire to take further ECE courses or to continue as (or transfer to) an electrical or computer engineering major. However, when compared with students in traditional sections, structured pairing students rated the ECE 110 laboratory as having a more positive impact on their desire to pursue a degree in engineering and take more electrical or computer engineering classes.

The College of Engineering enrollment data showed no significant difference in actual persistence between structured pairing and traditional section students. Structured pairing students were as likely as traditional section students to be engineering majors six months after completing ECE 110 and totake engineering courses the semester following ECE 110. Together with the marginally positive survey data, the enrollment data seem to show that structured pairing did not have a significant impact on student persistence within engineering. However, the data may be inconclusive.

Items 30 and 31 asked students to rate the impact the ECE 110 laboratory had on their desire to pursue a degree in engineering and to take more ECE courses or major in ECE. Table 3.1 shows that structured pairing students rated these two items significantly higher than did traditional section students. Thus, even though actual persistence did not significantly differ, structured pairing increased students' desire to persist within engineering. Limitations in the persistence data may account for the discrepancy.

Though courses taken the following semester and major after six months are the best measures of persistence I was able to obtain, they do not always accurately describe students' intended majors. An official change of major can take much longer than six months. Even if a student decided to change majors while taking ECE 110 in fall 2009, the official change may still not have taken effect by June 2010. In addition, though course selection demonstrates a student's intended major even if the official change has not occurred, not all engineering majors take an engineering course every semester. Some students might not have been able to fit desired engineering courses into their schedules, and some may have wanted to focus their studies elsewhere for a semester. Because of the unreliability of enrollment data, persistence may not have been accurately determined.

In addition, when compared with the pair programming study by McDowell et al., our students demonstrated stronger persistence overall. 71% of pair programmers and 42% of solo students who took the introductory computer science course intending to major in computer science remained computer science majors at University of California, Santa Cruz, one year after completing the course, whereas 90% of students in structured sections and 91% of students in traditional sections persisted within engineering six months after completing ECE 110. To put it another way, more than 100 from a subject pool of 238 initial computer science majors did not persist within computer science at Santa Cruz, whereas only 22 from our subject pool of 226 initial engineering majors did not persist within engineering at Illinois. Since persistence was so high at Illinois, there may not have been much room to improve.

5.2 Further Topics

Besides confidence, satisfaction, and persistence, I also investigated further impact structured pairing had on students. I included items on the end-of-semester survey that asked about teamwork, comfort with basic lab tasks, perceived workload and difficulty of lab work, and equity and positive experience in the lab. Student responses from the focus group expanded upon some of the survey results for these topics and introduced further benefits of structured pairing.

5.2.1 Teamwork and Group Relationships

Compared with students in traditional sections, students in structured sections felt as comfortable working with a partner or group in a laboratory setting and believed ECE 110 had a similar impact on their ability to work in a group in a laboratory setting. However, structured pairing students reported that they would be more willing to work with a partner or group in future engineering laboratories.

Based on focus group responses, structured pairing students had a stronger view of teamwork. Structured pairing students would take more time in lab to help their partners learn, whereas traditional section students were more concerned with completion and efficiency. This practice of mutual help and success could explain why structured pairing students expressed a willingness to participate in further group work.

Students also described their interpersonal relationships during the focus groups. Most students classified their relationships within lab groups as good or friendly, but some structured pairing and traditional section students experienced poor group relationships as well. Two students from structured sections had partners who participated very little in lab. Though one of the students accepted his partner's lack of participation, both students were displeased with their relationships by the end of the semester.

Even though these negative group experiences occurred during structured sections, the groups did not fully participate in structured pairing as they were instructed. In fact, all of the students from the focus groups who participated in structured pairing for any length of time experienced positive group relationships. Thus, structured pairing can help groups to form beneficial relationships, but only as long as students are willing to follow the protocol. In the future, steps should be taken to ensure stronger student participation.

5.2.2 Seeking Help

The end-of-semester surveys and focus groups showed that structured pairing students were more willing to participate in future group work and tended to have more positive experiences within their lab groups than did traditional section students. Based on the focus groups, structured pairing students also saw the benefit of seeking help from other groups, whereas traditional section students did not.

5.2.3 Basic Lab Skills

One of the purposes of structured pairing was to give students hands-on experience they might not otherwise obtain if they were free riders or if they worked in groups with dominant group leaders. In order to test whether students were gaining more hands-on experience, I included eight items regarding basic tasks within an engineering laboratory on the end-of-semester survey.

Structured pairing increased reported student comfort with six of the eight tasks. One of the two tasks for which structured pairing had no impact was checking voltages, currents, and resistances using a digital multimeter, the most basic and repeated task within the ECE 110 laboratory. Based on my experience as a TA, I surmise that even within the most dysfunctional groups, all students have had experience using the multimeters in the ECE 110 laboratory. Thus structured pairing should not have had any impact on students' comfort using multimeters.

I surmise that structured pairing students were more comfortable with the basic lab tasks than traditional section students because structured pairing helped students gain more hands-on experience in the laboratory than they would have by dividing labor freely.

5.2.4 Lower Perceived Workload and Difficulty

Students in both structured and traditional sections completed the same weekly lab assignments and the same final design project. According to the end-of-semester survey, however, structured pairing students perceived the workload in the laboratory, the difficulty of the weekly laboratory tasks, and the difficulty of the final design project to be lower than traditional section students. Thus structured pairing seems to make lab work less strenuous and difficult.

5.2.5 Equity and Positive Experience

Compared with students in traditional sections, students in structured pairing sections had more positive and equitable laboratory experiences. According to the end-of-semester survey, students in structured pairing sections were more pleased with their ECE 110 laboratory experience, were more likely to feel they had an equal part in their groups' success, were more likely to feel all members of their groups completed a fair amount of lab work, and were more likely to be proud of their work in the ECE 110 lab than were students in traditional sections.

In the focus groups, students from both traditional and structured sections claimed a mostly equal division of labor within their lab groups. However, students divided the labor in each type of section differently. Students in traditional sections divided work unsystematically. Whoever was closest to the desired piece of equipment or whoever was "in the mood" completed the task. By contrast, when they were not following structured pairing, students in structured sections divided labor by specialization. The more systematic approach of specialization can explain why students from structured sections perceived a more equitable experience.

5.3 Summary

In summary, structured pairing improves students' confidence in their laboratory skills and perceived ability to succeed in their engineering programs. It improves their satisfaction with their lab courses and the departments which host those courses. Though I was unable to prove that structured pairing improves persistence in the study of engineering, it did not discourage students from continuing towards engineering degrees.

Chapter 6: Conclusions and Future Work

Structured pairing is a way of structuring student groups in an engineering laboratory. In this study, I investigated the effectiveness of applying structured pairing to an undergraduate electronics laboratory. I found that structured pairing, like pair programming from which it was derived, improves student confidence, satisfaction, and desire to persist within engineering. Structured pairing also decreases perceived workload, increases confidence in basic lab tasks, inspires a stronger sense of teamwork, and facilitates a more positive and equitable lab experience.

In Chapter 1, I reviewed relevant literature on engineering and science laboratories. The literature described the importance of laboratory courses in engineering education and students' perceptions of those courses. Though there were few previous studies on how to structure student groups in engineering laboratories, literature in physics and computer science education provided some guidance. Students in physics laboratories tended to ignore complex roles within lab groups. Pair programming in computer science courses provided simple roles and demonstrated success in increasing student confidence, satisfaction, and persistence. Pair programming specifically benefited women and students with below average academic potential.

Based on pair programming, I created structured pairing, a method of organizing student groups suited for engineering laboratories. In Fall 2009, I implemented structured pairing in ECE 110, *Introduction to Electrical and Computer Engineering*. The laboratory portion of the course provided a convenient and feasible environment to apply structured pairing. For comparison, about half of the lab sections followed structured pairing while the other half operated traditionally.

I collected quantitative data through brief post-lab surveys and longer end-of-semester surveys, final exam grades, and College of Engineering enrollment information. I also collected qualitative data through two ninety-minute focus groups. The end-of-semester surveys indicated that structured pairing increased student confidence, satisfaction, desire to persist within engineering, confidence in basic lab skills, perception of teamwork, ease of workload, and feelings of a positive and equitable lab experience.

The focus groups revealed that structured pairing students had better developed ideas of teamwork, division of labor, seeking help, and ideal lab partners than did students from traditional labs. The focus group participants also identified some of the reasons groups in structured sections stopped switching, ideas to increase student participation, and students' perceived benefits of structured pairing: better lab partners and well-rounded lab experiences.

Since there was no significant difference in final exam scores or in student persistence in engineering, I also concluded that structured pairing did not adversely affect participants and that students in the traditional sections were not unfairly disadvantaged. However, traditional section students did not receive the same affective benefits as did structured pairing students.

Because structured pairing conferred so many affective benefits with no apparent disadvantages, it has become standard in the ECE 110 laboratory during the Spring and Fall 2010 semesters. Due to student confusion regarding the terms "driver" and "navigator," the term "driver" has been replaced by "pilot." In addition, teaching assistants have begun to stress to the students the benefits of structured pairing, such as increased confidence and satisfaction, and students are now graded based on their compliance with the switching of roles.

Though the topics, experiments, and equipment can vary greatly between engineering laboratories, I believe structured pairing can be implemented in most engineering labs. The structured pairing concept is simple and adaptable: one student performs the hands-on work while the other student(s) keep(s) the group on task. I hope structured pairing can be further studied in additional engineering laboratories.

Unfortunately, I was unable to answer all of my questions about structured pairing. The following is a list of questions that arose from my study that might be further investigated.

1) In pair programming, students switched roles every twenty minutes. In structured pairing, they switched at designated breaks in the lab procedures (15–40 minutes). Do the frequency and consistency of the transition points matter? Is it more important for students to experience an equal amount of time in each role or to complete specific tasks? Additionally, is there an ideal period for timed transitions?
2) In ECE 110, students worked in groups of two or three. Other laboratories may have larger group sizes. How does group size affect students under structured pairing? Is a group of two preferable to a group of three? Four?
3) I adapted structured pairing from computer science laboratories to an electronics laboratory. Could structured pairing be used in mechanical, civil, or other engineering laboratories with similar results?
4) Students are grouped together in engineering laboratories in three ways: randomly, by student choice, and by instructor matching. In ECE 110, students were allowed to choose their own groups. Could assigning students randomly or by some form of deliberate matching improve outcomes? For example, would students be better off if they were paired with other students of similar intelligence and skill, or should stronger students be paired with weaker students?

5) With the two focus groups, I was able to assess the experiences and feelings of students in traditional and structured pairing labs. However, the focus groups revealed the viewpoints of only a small portion of the students, and only at the end of the semester. I believe it would have been beneficial to gather the feelings and experiences of a larger number of students each week of the semester, as in a weekly student journal. Data from weekly journals would indicate why and when students stopped switching, what they liked about structured pairing, and what could be improved.

6) I initially had hoped to investigate the effect of structured pairing on individual student laboratory proficiency. Unfortunately, no reliable measure existed. Grades on the weekly labs and the final design challenge tend to be high with little variance. These grades also reflect theoretical knowledge and design ability more than lab proficiency. Grades among members of the same lab group are also strongly correlated. It could be beneficial to develop a standard skills exam or lab practicum for introductory electronics labs. The practicum would be an individual exam in which the student demonstrates proficiency with basic lab equipment (such as a digital multimeter and oscilloscope) and basic lab tasks (such as measuring current and wiring a linear circuit).

7) McDowell et al. [6] found that pair programmers were more successful than solo programmers in their second computer science courses. Does structured pairing prepare students better for future lab courses? Grades in future courses, interviews/focus groups, and surveys could be used.

8) The focus group participants explained some of the reasons students in structured sections stopped switching or did not switch at all. They also suggested some methods for

improving compliance with switching. There should be further investigation into why students stop switching and how compliance could be improved.

Appendix A: In-Lab Materials

1) Consent Form

Appendix A.1 contains the consent form given to students during their first lab session.

2) Structured Pairing Script

Appendix A.2 contains the script I gave to ECE 110 TAs to introduce structured pairing to their students.

3) Informal Post-Lab Survey

Appendix A.3 contains the informal, anonymous post-lab survey students completed voluntarily at the end of each lab period.

4) End-of-Semester Survey

Appendix A.4 contains the anonymous survey students completed voluntarily during the last laboratory meeting of the semester.

A.1: Consent Form

Pair Programming in the ECE 110 Laboratory

Consent Form for Students Who Are Enrolled in ECE 110

Michael C. Loui, Nicholas D. Fila
Fall 2009

Purpose and Procedures

The purpose of this research is to study the effects of assigning roles within lab groups in an electronics laboratory. In addition to your normal ECE 110 laboratory course work, in which you will participate in a group with or without assigned roles, you will be asked to complete a five to ten minute survey at the end of the semester and report your ACT-math score (on this form). In addition, final exam scores, scores on the final lab project (track score), a random sample of lab reports, and College of Engineering enrollment information for the Spring 2010 semester will be collected. Only data from students who consent to participation in this research study will be used. The consent forms will be kept by staff member Lila Rhoades and will not be delivered to Professor Loui until after he submits grades for the ECE 110 course.

Voluntariness

Participation in this research is voluntary. You may refuse to participate or may discontinue participation at any time, by completing and dating a new form, without penalty. Participation will not affect your grade in a course or status at this university.

Benefits and Risks

Those who participate in the sections with assigned roles may benefit from increased confidence and satisfaction with the coursework along with more positive views of group work. Risks are expected to be minimal.

Confidentiality

The data to be used in this research is limited to the end-of-semester survey, ACT-Math score reported on this consent form, final exam score, final track score, lab reports, and College of Engineering enrollment information. In the event of publication of this research, no personally identifying information will be disclosed.

Whom to Contact with Questions

Questions about this research should be directed to Michael Loui (loui@illinois.edu) or Nicholas Fila (nfila2@illinois.edu). Questions about your rights as a research participant should be directed to the campus Institutional Review Board at (217) 333-2670.

Check One Box

☐ I certify that I have read this form, and I volunteer to participate in this research study.

☐ I do not wish to participate in this research study.

ACT-Math score: __________

Please print name: ____

Signature: ____ Date: _____________________

A.2: Structured Pairing Script

This semester, we'll be trying something a little different in the ECE 110 lab. In six of the thirteen sections, including this one, we will be changing the way groups work together. In the past, students have divided up the tasks of each laboratory assignment freely among themselves. In some cases this has worked well, but in some cases students ended up being stuck completing the same set of tasks throughout the entire semester, never gaining experience in tasks that were essential to the introductory lab experience.

Based on pair programming research conducted in the computer science field, we are introducing what we've titled structured pairing. This involves you students acting in assigned roles within your lab groups for the duration of the lab assignments. There are two roles involved: the driver and the navigator. You can think of it kind of like rally cars. The driver does all of the hands-on work. This includes: wiring circuits, probing circuits, hands-on work with the car, drawing circuit diagrams, and adjusting instruments/equipment. The navigator is there to make sure you're going in the right direction. This involves constantly monitoring the driver's actions and the group's progress through the lab activities. This is the main role of the navigator, but navigators will also be recording values from the oscilloscope, multimeter, or any other measurement device. Both members of the lab groups will be responsible for gathering and putting away equipment, completing your own lab reports, talking about what you have done in lab, making design decisions, and drawing conclusions based on what you have done in lab.

The roles of driver and navigator will not be permanent. During each lab, we have chosen a number of switching points, which are written at the top of the white board. When you reach the question number listed, you should switch roles. Thus, driver becomes navigator and vice versa. Our main goal is to aid you through the course of the labs, and we will not be able to constantly monitor whether you're switching or not. So please be honest and diligent about switching roles. After all, it should be for your benefit.

We may end up with one or more group(s) of three in this section. In these cases, there will be one driver and two navigators at any one time. If you're in one of these groups, please make sure that everyone gets experience as both driver and navigator. You should each be the driver once in three rotations.

Based on the past research, we do not expect this process to affect your grade in this course, but there are many potential benefits including increased confidence and satisfaction. With that being said, if you are uncomfortable with the idea of structured pairing you still have the opportunity to switch lab sections.

If you have any questions or concerns regarding structured pairing, please feel free to contact Nick Fila, the TA who is coordinating this project, or Michael Loui, the faculty supervisor, whose e-mail addresses are listed on the white board. (nfila2@illinois.edu, loui@illinois.edu)

A.3: Informal Post-lab Survey

ECE 110 Post-Lab Survey

Section # or Date/Time:________ Lab #:__________

1) How confident are you in your solutions to the laboratory exercises? (Circle one)
   1 2 3 4 5 *(1 = not at all confident, 5 = very confident)*

2) How much did you enjoy working on this laboratory assignment? (Circle one)
   1 2 3 4 5 *(1 = very unenjoyable, 5 = very enjoyable)*

3) How satisfied are you with the outcome of this laboratory assignment? (Circle one)
   1 2 3 4 5 *(1 = very dissatisfied, 5 = very satisfied)*

4) **Structured Sections Only**: How often did you follow the outlined switch points? (Circle one)
   Not at all Some of the time All of the time Did not switch at all

5) Do you have any comments?

A.4: End-of-Semester Survey

We are gathering data for a research project to evaluate the effectiveness of the ECE 110 laboratory. All data on this survey will be kept confidential and will not be shared with ECE 110 instructors until after course grades are filed. This survey is anonymous; *do not write your name on this form*.

This survey should take approximately ten minutes to complete.

Section 1 of 8 (8 questions)
Background Information

Lab section:

Age:

Year in school (circle one): Freshman Sophomore Junior Senior

Current major:

Major at onset of semester (or, write "same"):

Sex: M F

Expected letter grade in course (see Mallard):

Expected grade on final track (0-10):

Size of lab group: 2 3

Section 2 of 8 (3 questions)
Please rate the following items using the scale below.

1………………..**2**………………..**3**………………..**4**………………..**5**

Not at all Confident **Moderately Confident** **Extremely Confident**

Confidence in my laboratory skills	
Confidence in my electrical and computer engineering knowledge	
Confidence that my car will complete the final track	

<u>Section 3 of 8 (3 questions)</u>
Please rate the following items using the scale below.

1……………….2……………….3……………….4……………….5
Completely Dissatisfied **Neutral** **Completely Satisfied**

Satisfaction with the lab portion of ECE 110	
Satisfaction with ECE 110 as a whole	
Satisfaction with the ECE program at Illinois in general	

<u>Section 4 of 8 (21 questions)</u>
Please rate your level of agreement with the following statements using the scale below.

1……………….2……………….3……………….4……………….5
Strongly Disagree **Neutral** **Strongly Agree**

I am pleased with my ECE 110 laboratory experience.	
Electrical engineering is an exciting field.	
Computer engineering is an exciting field.	
I am comfortable checking voltages, currents, and resistances using the digital multimeter.	
I am comfortable capturing signals using the oscilloscope.	
I am comfortable reading the frequency, period, and peak-to-peak voltage of a periodic signal using the oscilloscope.	
I am comfortable setting up a simple circuit using resistors and diodes.	
I am comfortable designing a circuit using simple logic elements.	
I am comfortable wiring a circuit using TTL logic gates from an existing design.	
I am comfortable wiring a circuit using TTL logic gates from my own design.	
I am comfortable debugging a circuit that includes TTL logic gates.	

I enjoyed working with my lab partner(s).	
I am comfortable working with a partner or group in a laboratory setting.	
I am comfortable working with a partner or group in a non-laboratory setting.	
I would be willing to work with a partner or group in future engineering laboratories.	
I participated in lab to the best of my ability.	
I feel like I had an equal part in my group’s success.	
Everyone in my group did their fair share.	
I am proud of the work I have done in ECE 110 lab.	
I plan to take more ECE courses beyond what is specifically required by my major.	
I plan to continue my ECE studies (or transfer into ECE).	

<u>Section 5 of 8 (3 questions)</u>
Please rate the following items using the scale below.

-2…………..…….1…………..…….0………….……..1..……………….2
much too low too low just right too high much too high

Workload in the ECE 110 laboratory	
Difficulty of the weekly laboratory tasks	
Difficulty of the final project	

<u>Section 6 of 8 (10 questions)</u>
Please rate the impact that participating in the ECE 110 laboratory has had on the following items using the scale below.

The ECE 110 laboratory has had a:
-2…………..……….1…………...…….0…………….…..1..……………..….2
very negative impact negative impact no impact positive impact very positive impact

Desire to pursue a degree in engineering	

Desire to take more ECE courses or major in ECE	
Confidence in my laboratory abilities	
Confidence in my electrical and computer engineering knowledge	
Confidence in my ability to achieve a degree in engineering	
Overall engineering knowledge	
Satisfaction with the ECE program at Illinois	
Perception of the ECE 110 course	
Ability to work in a group in a laboratory setting	
Ability to interact with peers	

Section 7 of 8 (1 question)

Taking into consideration the total time you spent working on the car design, what percentage of this did you spend working alone? Example: You worked 20 hours with your partner, and 10 hours working alone. So, you spent 10 of 30 hours, or 33 percent, working alone.

Approximately ______ percent

Section 8 of 8 (2 questions)
Structured Pairs Only

When you and your partner(s) worked together, what percentage of time did you adhere to the Structured Pairing protocol?

Approximately ______ percent

When you and your partner(s) worked together and adhered to the Structured Pairing protocol, what percentage of time did you spend driving?

Approximately ______ percent

Appendix B: Focus Group Materials

1) Focus Group E-mail Solicitation

Appendix B.1 contains the e-mail solicitation to introduce the focus groups to ECE 110 students.

2) Consent Form for Focus Groups

Appendix B.2 contains the consent form given to focus group participants.

3) Original Focus Group Protocol

Appendix B.3 contains the script of questions I originally intended to ask both focus groups.

4) Script of Questions to Traditional Focus Group

Appendix B.4 contains the entire list of questions Professor Loui and I asked the focus group of traditional section students.

5) Script of Questions to Structured Focus Group

Appendix B.5 contains the entire list of questions Professor Loui and I asked the focus group of structured pairing students.

B.1: Focus Group E-mail Solicitation

Former students of ECE 110 regular [or structured] lab sections:

I am writing to request your help with an important research project. The purpose of this project is to investigate the effects of structuring roles within lab groups in an electronics laboratory. Only students like you can provide the information needed to evaluate the structuring of lab groups in ECE 110.

You are invited to participate in a focus group interview consisting of students who participated in regular [or structured] lab sessions in ECE 110 in Fall 2009. Your focus group will run from 5:00 to 6:30 p.m. on Tuesday, January 26 [or Thursday, January 28] at Room 365 Everitt Lab. The session will be audio recorded. Pizza will be served at the beginning of the session. As a token of our appreciation, you will receive $10 at the end of the focus group session.

Your participation in this research will remain confidential. No personally identifying information will be disclosed. If you have any questions about the project, please contact me at loui@illinois.edu. If you are concerned about your rights as a participant, please contact the campus Institutional Review Board at (217) 333-2670 or irb@illinois.edu.

If you are interested in participating, please reply by e-mail to graduate teaching assistant Nicholas Fila at nfila2@illinois.edu by Thursday, January 21, 2010. Only twelve students will be selected for [each] focus group session, to represent the diversity of students in the entire class.

Sincerely yours,

Michael C. Loui
Professor of Electrical and Computer Engineering

B.2: Consent Form for Focus Groups

Pair Programming in the ECE 110 Laboratory: Consent Form for Focus Groups

Michael Loui and Nicholas Fila
University of Illinois at Urbana-Champaign
January 2010

Purpose and Procedures

This research study is being conducted by Professor Michael Loui and graduate teaching assistant Nicholas Fila. The purpose of this research is to investigate the effects of structuring roles within lab groups in an electronics laboratory.

You will participate in a focus group interview for about 90 minutes. The interview will be audio recorded.

Voluntariness

Participation in this research is voluntary. You may refuse to participate or may discontinue participation at any time. During the interview, you may skip questions that you prefer not to answer. Participation will not affect your grade in a course, status as a student, or future relationship with the University.

Compensation

In return for participation, you will receive $10 at the end of the focus group session.

Benefits and Risks

The Department of Electrical and Computer Engineering will benefit from accurate information about the experiences of students in ECE 110. Participants may benefit from reflecting on their experiences. Risks are expected to be minimal, no more than in everyday life.

Confidentiality

The audio recording of the interview will be used only for research purposes; it will not be disseminated. The data to be used in this research are limited to the interview text with associated demographic information. When the interview is transcribed, your name will be replaced by an identifying code. In the event of publication, no personally identifying information will be disclosed.

We expect each focus group participant to respect the confidentiality of the information gathered during the interview, but we cannot guarantee that individual participants will not later divulge information about what other participants said.

Whom to Contact with Questions

Questions about this research should be directed to Professor Michael Loui (phone 217-333-2595, e-mail loui@illinois.edu). Questions about your rights as a research participant should be directed to the campus Institutional Review Board (phone 217-333-2670, e-mail irb@illinois.edu); you may call collect.

I certify that I have read this form, I have received a copy of this form, I am 18 years of age or older, and I volunteer to participate in this research study.

Please print official name: ____

Signature: ____ Date: _____________________

B.3: Initial Focus Group Protocol

1) Please state your major, year in school, and the size of your ECE 110 lab group.
2) What was your most comfortable lab task?
3) What was your least comfortable lab task?
4) What was the best part of working in a group?
5) What was the worst part of working in a group?
6) Did you get along well with your partners?

   Follow-up) How did you resolve conflicts or disagreements?
7) Comment on the division of labor in your group.
8) If you could change one thing about how your group functioned/operated, what would that be?
9) If you had the 110 lab to do all over again, would you prefer a switching section or a standard section?
10) What was your favorite part of the ECE 110 lab?
11) What changes/improvements would you make to the lab?

B.4: Questions Asked During Traditional Focus Group

1) Please state your major, your year in school, and the size of your ECE110 lab group.

2) What lab task were you most comfortable with?

3) What lab task were you least comfortable with?

4) What was the best part of working in your lab group; what did you enjoy most working with your partners?

5) Was everyone happy with the number of people in their lab group?

6) How well did you get along with your partners?

7) How did you resolve conflicts or disagreements with your partners?

8) Comment on the division of labor in your group.

9) If you had to do the labs all over again, would you prefer to be in a structured pairing section or would you prefer to be in the standard section where you could divide up the labor however you liked and why?

10) A number of you have talked about whether your partner did the work or did not do the work. I'd just like you to explain what does "doing the work" mean or look like, what are tasks that you consider "doing the work"?

11) You've explained what "work" looks like and so not doing work would then be not contributing. I don't want to put words in your mouth, but just briefly, what does it mean to not do work?

12) What does a "good" partner look like?

13) If you could change any one, single thing about your ECE110 experience, what would that be?

14) What was your favorite part about the 110 lab?

B.5: Questions Asked During the Structured Focus Group

1) Please state your major, your year in school, and the size of your ECE 110 lab group.
2) What was your most comfortable lab task?
3) What lab task were you least comfortable with?
4) What was the best part of working in your lab group?
5) How well did you get along with your lab partners?
6) How did you resolve conflicts or disagreements with your partner or partners?
7) How closely did you actually follow the structured pairing protocol that was outlined by your TA's at the beginning of the lab?
8) A lot of you mentioned that [structured pairing] was either time-consuming or cumbersome and that's why you ended up dropping it towards the end of the semester. What specifically did you find time-consuming about it or cumbersome?
9) Describe your ideal lab partner.
10) Given the opportunity to change structured pairing, what would be one thing you would change about it?
11) What was your favorite part about the ECE110 lab?

References

[1] S. D. Sheppard, K. Macatangay, A. Colby, and W. M. Sullivan, *Educating Engineers: Designing for the Future of the Field*. San Francisco, CA: Jossey-Bass, 2009.

[2] D. Magin and S. Kanapathipillai, "Engineering students' understanding the role of experimentation," *European Journal of Engineering Education*, vol. 25, no. 4, pp. 351–358, Dec. 2000.

[3] A. A. Sutko, "Further study of the effect of group size on student performance," *Materials Research Society Proceedings*, vol. 632, pp. 88–91, 2000.

[4] P. Gresser, "A Study of social interaction and teamwork in reformed physics laboratories," Ph.D. dissertation, University of Maryland, College Park, MA, 2005.

[5] J. Lochhead and A. Whimbey, "Teaching analytical reasoning through thinking aloud pair problem solving," in *New Directions for Teaching and Learning*, no. 30, *Developing Critical Thinking and Problem-Solving Abilities*, J. E. Stice, Ed. San Francisco, CA: Jossey-Bass, 1987, pp. 73-92.

[6] C. McDowell, L. Werner, H. E. Bullock, and J. Fernald, "Pair programming improves student retention, confidence, and program quality," *Communications of ACM*, vol. 49, no. 8, pp. 90–95, Aug. 2006.

[7] G. Braught, L. M. Eby, and T. Wahls, "The effects of pair-programming on individual skill," in *Proceedings of the 39th ACM Technical Symposium on Computer Science Education*, 2008, pp. 200–204.

[8] R. B. Uribe, L. Haken, and M. C. Loui, "A design laboratory in electrical and computer engineering for freshmen," *IEEE Transactions on Education*, vol. 37, no. 2, pp. 194–202, May 1994.

[9] N. D. Fila and M. C. Loui, "Work-in-progress: Who's driving? Structured pairs in an introductory electronics laboratory," in *Proceedings of the Fortieth Annual Frontiers in Education Conference*, 2010, pp. FC3-1–FC3-2.

[10] A. L. Strauss and J. M. Corbin, *Basics of Qualitative Research: Grounded Theory Procedures and Techniques*. Newbury Park, CA: Sage, 1990.

[11] M. Davis, *Thinking Like an Engineer: Studies in the Ethics of a Profession*.New York, NY: Oxford University Press, 1998.

[12] R. M. Felder, G. N. Felder, and E. J. Dietz, "The effects of personality type on engineering student performance and attitudes," *Journal of Engineering Education*, vol. 91, no. 1, pp. 3–17, 2002.

[13] M. C. Loui, “Ethics and the development of professional identities of engineering students,” *Journal of Engineering Education*, vol. 94, no. 4, pp. 383–390, Oct. 2005.